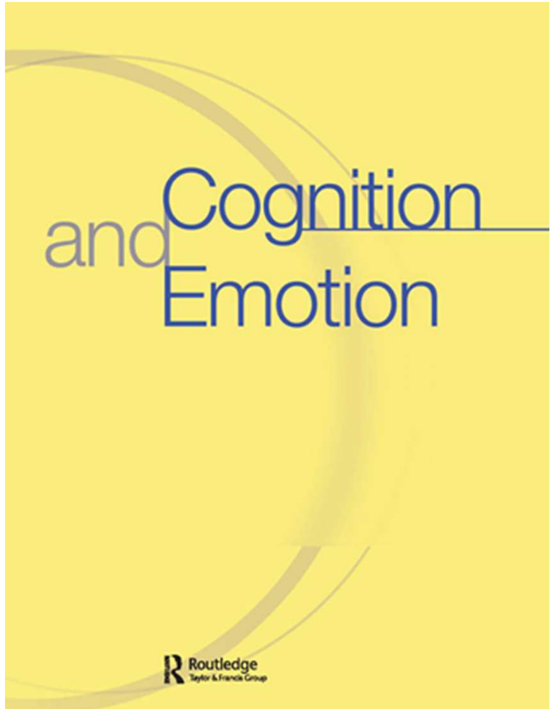

Mimicking emotions: How 3- to-12 month-old infants use the facial expressions and eyes of a model.

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Running head: EMOTIONAL MIMICRY IN INFANTS

Mimicking emotions: How 3- to-12 month-old infants use the facial expressions and eyes of a model

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Abstract

While there is an extensive literature on the tendency to mimic emotional expressions in adults, it is unclear how this skill emerges and develops over time. Specifically, it is unclear whether infants mimic discrete emotion-related facial actions, whether their facial displays are moderated by contextual cues and whether infants' emotional mimicry is constrained by developmental changes in the ability to discriminate emotions. We therefore investigate these questions using, Baby-FACS to code infants' facial displays and eye-movement tracking to examine infants' looking times at facial expressions. Three-, 7-, and 12-month-old participants were exposed to dynamic facial expressions (joy, anger, fear, disgust, sadness) of a virtual model which either looked at the infant or had an averted gaze. Infants did not match emotion-specific facial actions shown by the model, but they produced valence-congruent facial responses to the distinct expressions. Furthermore, only the 7- and 12-month-olds displayed negative responses to the model's negative expressions and they looked more at areas of the face recruiting facial actions involved in specific expressions. Our results suggest that valence-congruent expressions emerge in infancy during a period where the decoding of facial expressions becomes increasingly sensitive to the social signal value of emotions.

Keywords: Infant, emotional mimicry, facial expressions, gaze direction.

The ability to reproduce nonverbal displays of conspecifics, variously termed 'matching behavior', 'imitation' or 'mimicry', is rooted in the neonatal period. This imitative skill has been demonstrated in many studies for 'simple' oral and manual gestures (e.g., Meltzoff & Moore, 1977; Nagy, Pal, & Orvos, 2014; Reissland, 1988; Simpson, Murray, Paukner, & Ferrari; 2014; Soussignan, Courtial, Canet, Danon-Apter, & Nadel, 2011). Despite intense study of this topic, neonatal imitation is still hotly debated (e.g., Oostenbroek et al., 2016). Furthermore, neonatal ability to mimic facial expressions (i.e., emotional mimicry) remains unclear, with conflicting results (Field, Woodson, Greenberg, & Cohen, 1982; Kaitz, Meschulach-Sarfaty, Auerbach, & Eidelman, 1988; Oostenbroek et al., 2016). For instance, while Kaitz et al. (1988) found that newborns produce dynamically modeled tongue protrusion, they did not find that newborns imitate facial expressions of happiness, surprise or sadness as previously reported by Field et al. (1982). These partly discrepant findings suggest that emotional mimicry might differ from simpler forms of mimicry in terms of underlying perception-action mechanisms and of development. Indeed, emotional facial displays differ from other nonverbal behaviors in that only the former convey intrinsically meaningful signals providing information about a person's states of mind and intentions (Fridlund, 1994; Hess & Fisher, 2013).

Because of the lack of infant studies that rely on both highly controlled facial stimuli and precise coding of facial movements, the development of emotional mimicry remains poorly understood. Rather, infant studies have been up till now mostly based on infant responses to multimodal, visual and vocal emotional signals, during naturalistic face-to-face interactions with adults (e.g., Haviland & Lelwica, 1987; Izard, Fantauzzo, Castle, Haynes, Rayias, & Putnam, 1995; Montague & Andrews-Walker, 2001). Investigating the developmental differentiation in the production of facial expressions, this body of research has generated conflicting findings which we believe could be clarified using a different paradigm. The debate relates to various theories of emotional development, including gradual differentiation (Sroufe, 1996), dynamical systems (Camras & Shutter, 2010), functionalist perspectives (Barrett & Campos, 1987) and differential emotion theory (DET) (Izard & Malatesta, 1987). According to DET, human emotions are hard-wired with facial expression being a core component occurring without precursors within the first 6-7 months to reflect discrete emotions. Furthermore, the proponents of DET claimed that infants produce full-face expressions in response to specific situations that remain morphologically stable during infancy. In contrast, alternative theoretical frameworks emphasize flexibility in the organization of emotional responses during infancy (Camras & Fatani, 2008). Instead of considering infant facial expressions as an automatic readout of discrete emotions to different eliciting stimuli, differentiation theorists (e.g., Sroufe, 1996) propose a valence-based distinction in the production of expressions accompanying specific emotions after the first 6 months, while functionalist or dynamical system theorists (Barrett & Campos, 1987; Camras & Shutter, 2010) stress variability in infants' facial expressions (e.g., blended expressions, no one-to-one expression-experience relationship, lack of situational specificity) reflecting the appraisal of the relevance of an event to a person's goals or heterochronicity in the development of the components of emotion.

Based on the assumptions of DET, the Maximally Discriminative Facial Movement Coding System (MAX; Izard, 1979) was developed to derive templates from adult prototypes to identify infant facial expressions and infer their corresponding emotions. While some studies reported direct interpersonal matching and morphological stability for some MAX-specified facial expressions, such as joy, anger, sadness, surprise, over the first 9 months (Haviland & Lelwica, 1987; Izard et al., 1995; Termine & Izard, 1988), other studies did not confirm that infants mirrored adult expressions (D'Entremont & Muir, 1999; Montague & Walker-Andrews, 2001; Oostenbroek et al., 2016). Furthermore, studies of facial expressions in both social and non-social settings provide little evidence that young infants display discrete emotions. Rather, infants show blended facial expressions and subtle variants of positive and negative expressions (Bennett, Bendersky, & Lewis, 2005; Camras et al., 2007; Oster, Hegley, & Nagel, 1992). Studies on adult-infant interactions have not, however, tested whether infants develop the ability to mimic adult facial expressions from early to later infancy and whether the development of emotional mimicry is related to an infant's ability to discriminate emotions.

Theoretical frameworks of emotional mimicry

Emotional mimicry, like other forms of mimicry, fosters affiliation and bonding (Chartrand & van Baaren, 2009). However, underlying mechanisms and the nature of information shared between the sender and the receiver are still debated (Hess & Fisher, 2014). The classical view on mimicry, based on the matched motor hypothesis (MMH), argues that there is a perception-behavior link (Chartrand & van Baaren, 2009): perceiving another's behavior automatically activates the perceiver's motor representation of that behavior via the so-called mirror neuron system (MNS) (Rizzolatti & Craighero, 2004). Thus, although mimicry may be moderated by various factors (e.g., direct gaze; Wang, Newport, & Hamilton, 2011), this model states that looking at a person displaying facial expressions of emotions triggers in the perceiver specific facial movements which reflect these emotions, even when these expressions are subliminally presented or when people try to control facial mimicry (Dimberg, Thunberg, & Elmehed, 2000; Dimberg, Thunberg, & Grunedal, 2002). Hence, from this perspective, emotional mimicry is a particular form of behavioral mimicry.

As an alternative to the MMH, a contextualized view of emotional mimicry has been proposed (Hess & Fisher, 2013, 2014). Rather than positing an accurate matching of the modeled expressions, it is suggested that people appraise the meaning of an emotional signal conveying an intention in a social context, and that they establish an affiliative connection with the other person by sharing a valenced-based expression rather than specific facial movements corresponding to a discrete emotion. In this framework, people appraise facial movements expressing, for example, sadness and then display a negative expression rather than copying the specific facial pattern displayed by the sender (Hess & Fisher, 2014). Furthermore, concerning contextual information, gaze direction may be used as a cue to appraise the intention of the sender rather than to modulate facial mimicry. Gaze is crucial because a perceiver infers from it the locus of interest which combined with the sender's emotional expressions informs about intentions (Emery, 2000). The role of gaze in the processing of emotional expressions has been elaborated in both the shared signal hypothesis and appraisal theories (Adams & Kleck, 2005; Rigato, Farroni, & Johnson, 2010; Sander, Grandjean, Kaiser, Wehrle, & Scherer, 2007). Although these two views differ in terms of underlying processes (i.e. congruency between gaze and intent communicated by an emotion; self-relevance of gaze with regard to its signaling value), both predict that approach-related emotions (joy, anger) would be facilitated when gaze is direct rather than averted, whereas avoidance-related emotions (fear, sadness) would be facilitated if gaze is averted rather than direct. For example, in adults, direct gaze enhances the perceived intensity of anger and joy expressions, whereas averted gaze enhances the perceived intensity of fear and sadness expressions (Adams & Kleck, 2005).

Aims and hypotheses of the present research

Theoretical models of emotional mimicry as well as previous research suggest several possible phenomena that might be observed: 1) infants could mimic emotion-specific facial actions or they could display an emotion congruent only with the valence of the modeled emotion without exactly copying facial actions (i.e., a valence-congruent expression); 2) infants' attention to facial expressions and production of emotional mimicry could change across development because the ability to discriminate emotional expressions improves between early and late infancy (Leppänen & Nelson, 2009); 3) infant facial responses could be moderated by the gaze direction. The present paper addreses these topics by testing 3, 7 and 12 month-old infants'ability to produce congruent facial responses after watching a human virtual model displaying dynamic facial expressions of joy, sadness, anger, fear, and disgust. We used virtual models as they allow a strict control of both facial actions and gaze direction of the sender. Furthermore, we recorded infants' eye movement while viewing the model's facial expressions to investigate whether infants looked at emotionally-relevant regions of the face when displaying congruent actions to the model's expressions.

Based on the MMH, one might predict a relatively rigid perception-action coupling, in that infants are expected to mimic emotion-related facial actions regardless of age, with direct gaze enhancing emotional mimicry. In contrast to the MMH, we favor a contextualized view of emotional mimicry predicting that, depending on infants' socio-cognitive abilities, they would show valence matching rather than emotion-specific facial mimicry when exposed to emotional expressions. Given the developing ability to discriminate negative expressions during late infancy (Leppänen & Nelson, 2009), we expected that 7- and 12-month-olds, but not 3-month-olds, would display negative expressions to the modeled emotions. This prediction is also consistent with research reporting a discrepancy between the infants' ability to discriminate distinct emotional expressions when perceiving others (Leppänen & Nelson,

2009) and their production of facial expressions which are non-specific to discrete emotions (Camras & Shutter, 2010). However, concerning positive expressions, regardless of age, we predicted that infants would display congruent facial reactions (smiles) when they passively watch a repetitive sequence of a model's joy expression, since research shows that 2-3 month-old infants show contingent smiles during face-to-face interactions (Bigelow & Rochat, 2006; Soussignan, Nadel, Canet, & Gerardin, 2006).

Regarding infant attention, we expected that infants will look longer at joy expressions compared to neutral ones (LaBarbera, Izard, Vietze, & Parisi, 1976), with an increased looking time toward the region containing emotion specific information (mouth). Since, after 5 months, infants can discriminate negative facial expressions (Kotsoni, de Haan, & Johnson, 2001; Leppänen & Nelson, 2009), and are biased to attend to fearful faces (Peltola, Leppänen, Mäki, & Hietanen, 2009), we predicted that only 7- and 12-months-olds should display increased interest for negative expressions, particularly for fear faces and related facial regions (eyes).

Finally, consistent with the contextualized view's proposal that gaze direction may be a cue to appraise the meaning of an emotional signal, we predicted that infants will show a developing ability to process gaze direction in emotional faces (Flom & Johnson, 2011; Hoehl & Striano, 2008). As 3-month-olds are already sensitive to adult gaze during positive exchanges (Hains & Muir, 1996), all age groups should display more positive responses to the model's joy face with direct gaze. Regarding anger, we hypothesized that 7- and 12-month-olds would show more negative expressions to the model's anger face with direct than averted gaze because neural processing of angry faces has been reported in infants older than 3 months when these expressions were accompanied by direct gaze (Striano, Kopp, Grossmann, & Reid, 2006). For fear, sadness, and disgust, no predictions were made because current studies of 3- and 7-months-olds do not allow clear conclusions concerning sensitivity to gaze, in particular when infants cannot identify the source of the emotional display (Hoehl & Striano, 2008, 2010).

Methods

Participants

The sample comprised 104 infants consisting of 36 3 month-old (age: *M* =3.07 months, *SD* = 3.26 days; 18 females), 35 7 month-old (age: *M* =7.15 months, *SD* = 3.19 days; 18 females) and 33 12 month-old infants (age: *M* =12.21 months, *SD* = 2.90 days; 17 females). All infants were healthy, of normal birth weight (> 2150 g), with Apgar scores greater than 7 at 5 min after birth. Parents gave written consent for their participation. They were present during testing and informed that they could request cessation of the experiment at any time. All tests were ethically conducted under the Declaration of Helsinki for experimentation with human participants.

Facial stimuli

We created silent movie clips of two 3D virtual models' face, one male and one female, displaying five dynamic expressions, namely anger, disgust, fear, joy, sadness and one static neutral face, with either a static direct or a static averted gaze. These facial expressions were generated with the Poser 9 software by manipulating polygon groups comparable to the action units (AUs) described in the FACS (Ekman & Friesen, 1978). A certified FACS coder manipulated AUs corresponding to prototypical expressions by using the following codes (Ekman & Friesen, 1978): AUs 6 (cheek raiser) +12 (lip corner puller) +25 (lips part) for joy, AUs 4 (brow lowerer) +24 (lip pressor) for anger, AU 9 (nose wrinkle) for disgust, AUs 1+2 (brow raiser) +4+5 (upper lid raiser) +20 (lip stretcher) for fear, and AUs 1 (inner brow raiser) +4+15 (lip corner depressor) for sadness. Gaze direction was created by angular deviation of the iris/pupilla structures relative to the axis of the head, using a computational displacement of 15° to either side (left/right) to generate counterbalanced conditions. Each movie clip, which lasted 2 s, began with the model posing a neutral expression, with the expressive apex occurring at 500 ms, followed by a 1500 ms static expression. These movies were mounted on a black background and had a resolution of 1025 × 1050 pixels corresponding to 28.9 cm width and 29.6 cm length once displayed on the monitor. Adult judges confirmed that these expressions were accurately decoded and that gaze direction was accurately detected regardless of the type of emotion (Soussignan et al., 2013).

Procedure

The experiment took place in a dedicated baby-lab. On arrival, the experimenter explained the procedure to parents while an assistant played with the infant. When the infant appeared relaxed, s/he was comfortably secured in a baby car-seat, in a semi-reclining position. We presented stimuli on a 22-inch monitor at 1680 x 1050 pixels, using an eye-movement tracking system (RED250, SensoMotoric Instruments GmbH, Teltow, Germany) mounted just below it. We recorded the infant face using a video camera mounted on the top of the monitor and their face was positioned about 60 cm from the eye tracking system and about 65 cm from the camera. The parent was asked to stay silent and immobile 1.5 m behind the infant. Each infant passed a calibration test and then the experiment. The experimenter provided the stimuli during the calibration and testing and monitored the infant's behavior.

Calibration

A moving noisy cartoon figure appeared on the screen. When the infant looked at it, the experimenter moved the figure to a different position on the screen where it remained until the infant fixated it. Up to 5 locations covering the whole surface of the screen were tested. If the eye-tracking system failed to detect the infant's eyes for one or more of these locations, the calibration procedure was rerun.

Testing

Each infant completed 12 trials corresponding to either a male or a female virtual model displaying 5 expressions (anger, disgust, fear, joy, sadness) or remaining neutral, with the gaze either direct or averted, using the ExperimentCenter software. During each trial, the same 2-s animated sequence was repeated 3 times. The 6-s trials were randomly presented with a 3-s inter-trial interval during which a blue screen was displayed to signal the end of trial. The model's gender was counterbalanced with half of participants seeing the female and half the male model. For each infant, the orientation of the model's averted gaze was counterbalanced between trials with 6 of 12 trials testing direct gaze, 3 testing averted gaze to the right and 3 testing averted gaze to the left.

Behavior Recording

Eye movements of infants were followed for each eye with a sampling rate set at 250 Hz by using the SMI eye-movement tracking system during the trials displaying the facial stimuli. Eye-movement data were extracted off line for both eyes using the BeGaze Software. Infants' facial responses to facial stimuli were recorded with a video camera. These recordings were analyzed offline, using Baby FACS, to score infants' facial responses contingent to the models'emotional expressions.

Data Analysis

Baby FACS

Two certified FACS coders scored infants' facial behavior using the Baby FACS (Oster, 2007). The first coder who scored all the videoclips was blind to the presentation order of stimuli. The second coder, who was unaware of the aims/hypotheses and of the nature and order of stimuli, viewed a sample of 42 videotaped segments representing facial responses of 42 infants (14/age group; 7 females/group).

Infant facial behavior was coded frame by frame after the end of a blue signal (start time) during the 6-s sequence of each trial. Facial mimicry was based on the reproduction of partial or full-blown expressions of the model by coding the apex of each facial movement produced by the infant in response to the model. The following AUs were used as matching responses of corresponding emotional expression displayed by the model: lip corner pulling/smiling (AU 12) for the joy face (AUs 6+12+25); either brow lowering (AU 4) or lips pressing (AU 24) for anger face displays (AUs 4+24); for sad face displays (AUs 1+4+15), either brow raising and brow pulled together (AUs 1+4) or lip corner depressing (AU 15); partial (AUs 1, 2, 1+2, 1+2+4) or complete eyebrow raising with upper lid raising (AUs 1+2+4+5) accompanied or not by lip stretching (AU 20) for fear face displays (AUs 1+2+4+5+20); and nose wrinkling (AU 9) for disgust face (AU 9).

Negative expressions were defined using the following AUs (Camras et al., 2007; Rosenstein & Oster, 1988; Soussignan & Schaal, 1996): 4 (brows lowered), 1+4 (inner portions of brows raised and pulled together), 3+4 (brows knotted and knitted), 1+2+4 (entire brows raised), 9 (nose wrinkled), 10 (upper lip raised), 11 (nasolabial furrow deepened), 14 (lip corners tightened), 15 (lip corners pulled down), 17 (chin raised), 20 (lip stretched), and 23/24 (lip pressed/tightened).

We calculated the percentage of infants displaying emotion-congruent AUs (using the AU matching criteria described above) and the percentage of infants displaying positive and negative facial expressions (i.e., any type of negative AU as described above). Interobserver reliability was defined as the number of AUs on which both coders agreed multiplied by 2 and then divided by the total number of AUs scored by both coders (Ekman & Friesen, 1978). The percentage of agreement for the total number of AUs was 86 %. Interobserver agreements for the positive and negative expressions were 82 and 87 %, respectively.

Video coded attention

From videoclips, we coded duration of infants gaze at facial stimuli during each trial (in s) and we computed, as the dependent variable, the percentage of looking time by dividing the length of time infants looked at the screen by the duration of stimulus. Interobserver reliability was assessed between the main coder and a second coder who was blind to the order of stimuli presentation and who independently scored 10% of videoclips. Interobserver reliability using Pearson r correlation was 0.94 for the percentage of looking time.

Eye-movement tracking analysis

From the full sample of infants (n=104), 23 participants were not considered for eye-tracking analyses because the tracking system was unable to detect their gaze (n=7), because insufficient precision of gaze calibration (i.e. > to 2.5° on one of both axis) (n = 14) or because of insufficient duration of gaze detection (i.e. less than a third of the experiment duration) (n = 2). The remaining groups of 3-, 7-, and 12-month-olds comprised 17, 34, and 30 participants, respectively. To analyze infants' eye movement, we defined four areas of interest (AOIs), including the eyes and eyebrows, the nose, the mouth and external features. Figure 1 illustrates these AOIs on models' faces. Those AOIs were based on the face regions attracting infants' attention (as shown in preliminary analyses) and corresponding to AUs conveying emotional information (i.e., eyes and eyebrows for fear and anger; nose for disgust; and mouth for joy, anger and sadness) (see Supplementary Table 1).

Figure 1

Results

Infants' expressive matching to the model's facial expressions was demonstrated when both the criteria of inter-situational specificity and intra-situational specificity were met (Hiatt, Campos & Emde, 1979) using Cochran Q tests separately for each age group. For the first criterion, the percentage of infants displaying emotion-specific facial actions in response to the model must significantly exceed the percentage of infants who displayed the same facial responses to the other displayed-emotion conditions (e.g., the percentages of infants who smiled were compared between the 12 emotional stimuli). For the second criterion, the "hit" rate (i.e., the percentage of infants demonstrating the predicted facial components) must significantly exceed the "false response" rate (i.e., the percentages of infants demonstrating nonpredicted components) for each displayed-emotion condition (e.g., the percentage of infants who smiled was compared to the percentages of infants who displayed the non-predicted components (AU4+24, AU9, AU1+2+5+20, AU1+4+15) when infants were exposed to the joy expression of the model). Following significance, we applied McNemar tests to compare each pair of facial stimuli. We used Chi-square tests to examine whether the percentage of infants displaying matched AUs was related to infants' age. Although our large number of comparisons suggest that a corrected p-value of 0.01 would be appropriate, we choose to report all comparisons with $p < .05$ in the interest of presenting a more complete picture of the data. Furthermore, this approach is consistent with recommendations made by statisticians (Feise, 2002; Perneger, 1998; Rothman, 1990).

Emotion-congruent facial actions in response to distinct facial expressions

Table 1 presents the numbers and percentages of infants who displayed emotion-congruent facial actions in response to the distinct facial expressions of the models using the criteria of both inter-situational specificity (involving inter-task comparisons) and intra-situational specificity (involving intra-task comparisons). As can be seen these two criteria reach significance only for the models' joy expression. For the inter-task comparisons, the percentage of 3-month-olds who smiled (41.7%) to the models' joy face with direct gaze exceeded those who smiled to the models' neutral and negative expressions (with direct or averted gaze), $Q(11) = 33.89$, $p < .001$; Mc Nemar test, *ps* < .05. There were also more 3-month-olds displaying smiles to the models' joy face with averted gaze (25%) than to the models' anger face with direct gaze (5.5%), $p = .04$. The percentage of 7-month-olds who smiled was also affected by the models' expressions, $Q\ (11) = 19.5$, $p = .05$, but the Mc Nemar test revealed only a trend to significance. For the 12-month-olds, more infants smiled to the joy face (direct gaze: 27.3%; averted gaze: 33.3 %) compared to the other emotional expressions, $Q\ (11) = 34.46$, $p < .0001$; Mc Nemar test, *ps* < .05.

For the intra-task comparisons, the percentage of 3-month-olds who smiled when exposed to the models' joy face with direct gaze was higher compared to same-age infants who displayed the nonpredicted facial responses corresponding to each negative expression (anger, disgust, fear, sadness), ($Q(4) = 38.15$, $p < .001$, Mc Nemar test, *ps* < .0001. More 3-month-old infants also smiled when exposed to the models' joy face with averted gaze compared to those who displayed the nonpredicted actions of other facial expressions (Q(4) = 18.05 , $p < .01$, Mc Nemar test, *ps* < .05. For 7-month-olds, a higher percentage of infants smiled compared to those who displayed the nonpredicted actions of other facial expressions when exposed to the models' joy face with direct gaze, $Q(4) = 15.67$, $p < .003$, Mc Nemar test, *ps* < .05) or averted gaze ($Q(4) = 14.13$, $p < .006$, Mc Nemar test, *ps* < .05). For 12-month-olds, more infants also smiled compared to those who displayed nonpredicted actions corresponding to other facial expressions when exposed to the models' joy face with either direct gaze, ($Q(4) = 23.81$, $p < .0001$, Mc Nemar test, *ps* < .05) or averted gaze (Q(4) = 23.61, $p < .0001$, Mc Nemar test, *ps* < .01).

Concerning each negative expression displayed by the model (anger, disgust, fear, sadness), although a significant effect was detected in 7-month-olds in the inter-task comparisons, Q (11) = 25.08, p =.009, no emotional matching effect was found. Indeed, more infants showed anger faces (AUs 4/24) in response to the characters' sad face with averted gaze (22.85%) than to the neutral (direct gaze: 5.55%, p = .03; averted gaze: 0%, p = .008) and joy faces (direct gaze: 2.86%, p = .04; averted gaze: 0%, p = .008). A higher percentage of infants also displayed anger faces to the models' sad face with averted gaze than to the models' disgust (2.86%, p = .04) and sad faces with direct gaze (2.86%, p = .04). In the inter-task comparisons, a significant effect was also detected in the 7-month-olds who displayed fear faces (AUs1+2+4+5+20), Q (11) = 23. 91, p =.01. However, there was no emotional matching since more infants displayed components of fear faces when exposed to the models' neutral, anger and sad faces with averted gaze than to the models' joy and disgust faces with direct gaze.

Finally, an age effect was detected indicating that 3-month-olds smiled more than 7 month-olds to the joy face with direct gaze, χ^2 (2, N = 104) = 6.57, p =.03.

In summary, based on the two criteria of inter-situational specificity and intra- situational specificity, our results do not provide evidence that infants displayed emotion-specific facial actions in response to facial expressions of the model. There was only evidence that, regardless of age, infants displayed positive responses to the joy face of the model.

Table 1

Negative facial displays

The percentage of 3-month-olds displaying negative AUs did not change as a function of the models' facial expressions with direct or averted gaze, Q (11) = 13.15, p = .28. As can be seen from Table 2, these infants showed negative facial responses when exposed to both neutral and negative expressions of the model (direct or averted gaze) or to the joy face with averted gaze. In contrast, significant effects were found for both 7-month-olds, Q (11) = 32.40, p = .001, and 12-month-olds, Q (11) = 23.61, p = .01, with about 30 to 50% of infants displaying negative AUs to the negative expressions of the model. In 7-month-olds, more infants showed negative AUs to the model's sad face with averted gaze than to joy (direct gaze, p = .001; averted gaze, p < .001), anger (direct gaze, p = .02; averted gaze, p = .05), and disgust faces (direct gaze, p = .05; averted gaze, p = .01) or to the neutral (p < .0001), fear (p = .006), and sad faces (p = .01) with direct gaze. Further, more 7-month-olds displayed negative AUs to the model's fear face with averted gaze than to the joy faces (direct gaze, p = .04; averted gaze, p = .02), and more infants of this age group displayed negative AUs to anger faces with direct (p =.04) or averted (p = .04) gaze than to the joy faces with averted gaze. Interestingly, 12-month-olds displayed a more differentiated pattern compared to 7-month-olds as they showed negative AUs to the distinct negative expressions. Specifically, more 12-month-olds displayed negative AUs to the models' anger face with direct gaze than to their neutral faces (direct gaze, p = .02; averted gaze, p = .04), and to their joy face with direct gaze (p =.02). Additionally, more 12-month-olds displayed negative AUs to the disgust expression with direct gaze compared with the neutral (p = .04) and joy (p = .04) faces with direct gaze, and to the fear faces with direct gaze compared with the joy (p = .04) faces with direct gaze. Finally, 12-month-olds responded more to the sad face with averted gaze than to the neutral (p = .04) and joy (p = .04) faces with direct gaze.

A significant age effect in response to the neutral face with direct gaze, χ^2 (2, N=104) = 6.58, p =.037, indicated that more 3-month-olds (33.3%) than 12-month-olds (9%) displayed negative AUs for this expression, χ^2 (1, N=69) = 5.95, p =.01. The 3-month-olds also displayed more negative AUs to the joy face with averted gaze (27.8%) than 7-month-olds (5.7%), χ^2 (1, N=71) = 6.15, p =.01.

In summary, 12-month-olds, and to a lesser extent 7-month-olds, displayed valence-congruent expressions, with the oldest infants being more reactive to the distinct negative expressions of the models (anger, disgust, fear, sad faces), whereas the 7-month-olds were reactive to the anger, fear and sad faces of the models.

Table 2

Video-coded attention

An ANOVA with Age as a between-subjects factor and Emotion and Gaze of the model as within-subjects factors was conducted on the infants' percentage of looking time at facial stimuli. Infants' gender was not included because previous analyses did not reveal significant effects. Tukey's HSD tests were conducted as post-hoc tests. There was a main effect of Emotion, $F(5, 505) = 9.83$, $p < .0001$, $\eta_p^2 = .09$, reflecting longer looking time at the models'joy faces (M = 92.47%, SD = 11.1) than at their neutral (M = 83.50%, SD = 14.61, $p <$ .0001), anger (M = 84.75%, SD = 16.47, $p < .0001$), disgust (M = 87.60%, SD = 13.52, p = .01) and sad faces (M = 87.71%, SD = 13.33, p = .02). Further, infants attended longer to the fear (M = 90.21%, SD = 13.65) than to the neutral ($p < .0001$) and anger faces (p = .004).

Emotion x Gaze ANOVAs carried out within each age group did not reveal a significant main effect of Emotion in 3-month-olds, $F(5, 175) = 1.43$, p =.21, $\eta_p^2 = .04$. In contrast, a main effect of Emotion was found in both 7-month-olds, $F(5, 170) = 4.26$, p =.001, $\eta_p^2 = .11$, and 12-month-olds, $F(5, 160) = 5.49$, $p < .001$, $\eta_p^2 = .15$. These findings reflect longer looking time 1) in 7-month-olds to joy and fear than to neutral faces (p = .0004 and p = .048 respectively) and to joy than to anger faces (p= .04), and 2) in 12-month-olds to joy and fear faces than to neutral (p = .003 and p = .004 respectively) and anger faces (p = .004 and p = .005 respectively) (Figure 2).

Figure 2

Eye-movement tracking

ANOVAs were performed on the infant looking time (in ms) to each AOI of the models' face, with Age as a between-subjects factor, and Emotion and Gaze of the models as the within-subject factors. Infant's gender was not included because preliminary analyses did not reveal significant effects. Post-hoc tests were run using Tukey HSD tests. The mean durations of infant looking at each AOI of the models' face (eye, nose, mouth, and external features) are shown in Figure 3.

For the eye region, there was a significant effect of Emotion, $F(5, 390) = 9.64$, $p < .0001$, $\eta_p^2 = .11$, with an Emotion x Age interaction, $F(10, 390) = 2.68$, $p = .003$, $\eta_p^2 = .06$. ANOVAs performed within each age group indicated that the effect of Emotion was significant for 7-month-olds, $F(5, 165) = 7.45$, $p < .0001$, $\eta_p^2 = .18$, and 12-month-olds, $F(5,145) = 9.18$, $p < .0001$, $\eta_p^2 = .24$, but not for 3-month-olds, $F(5,80) = 1.32$, $p = .26$, $\eta_p^2 = .07$. Post-hoc tests indicated that the 7-month-olds looked longer at the eye region of angry ($p < .0001$), fearful ($p < .0001$) or sad faces ($p = .002$) than at the eye region of joy faces. They also looked longer at the eye region of the fearful than of the neutral faces ($p = .007$). For 12-month-olds, the eye region was looked at longer for fearful faces than for angry ($p < .001$), disgust ($p < .001$), joy ($p < .0001$), neutral ($p < .0001$) or sad faces ($p < .001$).

For the nose region, the main effect of Emotion, $F(5, 390) = 5.79$, $p < .0001$, $\eta_p^2 = .07$, and the Emotion x Age x Gaze interaction were significant, $F(10, 390) = 1.88$, $p = .046$, $\eta_p^2 = .05$. An Emotion x Gaze ANOVA performed on each age group revealed a main effect of Emotion for 7-month-olds, $F(5, 165) = 3.67$, $p = .004$, $\eta_p^2 = .10$, and 12-month-olds, $F(5, 145)$

= 4.88, p = .003, η_p^2 = .14, but not for 3-month-olds (F<1). The 7-month-olds looked more at the nose area of the joy than of the anger (p = .046) and fear (p = .025) faces. The 12-month-olds looked more at the nose area of the disgust (p = .002) and joy faces (p = .03) than of the fear faces, and at the nose area of the disgust than of the anger (p = .004) and neutral faces (p = .001). Moreover, an Emotion x Gaze interaction was found in 12-month-olds, F(5, 145) = 2.57, p =.03, ηp^2 = .08, revealing longer looking time at the nose area of the disgust than of the neutral (p = .01) and fear faces (p = .01) when the gaze was direct.

For the mouth region, a significant effect of Emotion, F(5, 390) = 11.67, p < .0001, η_p^2 = .13, indicated that infants looked at this area longer when they were exposed to the models'joy faces than to the other facial stimuli (ps <.0001, Tukey tests). Although the Emotion x Age interaction was marginally significant (F(10, 390) = 1.68, p = .08, η_p^2 = .04), two-way ANOVAs revealed that the effect of Emotion was significant only for 7- and 12-month-olds, F(5, 165) = 7.84, p <.0001, η_p^2 = .19 and F(5,145) = 8.89, p <.0001, η_p^2 = .23, respectively: they looked longer at the mouth of the models' joy faces when compared to the other stimuli (7-month-olds: anger, p < .0001; disgust, p = .001; neutral, p < .0001; fear, p < .0001 , sad, p < .0001; 12-month-olds: anger, p < .0001; disgust, p < .0001; neutral, p < .0001; fear, p < .0001, sad, p = .05).

For the external features, there was only a main effect of Age (F(2, 78) = 15.56, p <.0001, η_p^2= .29) indicating that 3-month-olds looked longer at the external features than 7- and 12-month-olds (ps <.001).

Figure 3

Discussion

This study assessed whether infants mimic emotion-specific facial actions or display valence-congruent expressions when seeing distinct facial configurations expressed by an avatar. It also examined whether this ability was related not only to the gaze direction of the model, but also to the infants' ability to discriminate facially-expressed emotions. This research adds to the literature because it is the first study using conjointly fine-grained analyses of perception (eye-movement tracking) and facial movement (Baby-FACS) to developmentally investigate in the same time visual attention for facial expressions and facial responsiveness in 3-to-12 month-old infants.

Do infants mimic emotion-specific facial actions or display valence-congruent expressions?

Consistent with the contextualized view of emotional mimicry (Hess & Fisher, 2013), and in contrast to the MMH (Chartrand & van Baaren, 2009), our study indicates that infants displayed valence-congruent expressions rather than emotion-specific facial actions when they passively watched modeled facial expressions. We found no evidence of either inter-situational or intra-situational specificity when the infants looked at distinct facial expressions of negative discrete emotions (anger, disgust, fear, and sadness) of virtual models. A lack of inter-situational and intra-situational specificities for infants' facial expressions has been reported during procedures designed to elicit anger or fear (arm restraint, growling gorilla situations) (Camras et al., 2007). Naturalistic research during face-to-face interactions has also shown that 4- and 5-month-olds do not mirror facial and vocal expressions of adults (D'Entremont & Muir, 1999; Montague & Walker-Andrews, 2001). These results may reflect either a lack of pre-specified facial expressions invariably reflecting a set of discrete emotions during the first year of life (Camras & Shutter, 2010), or the fact that seeing someone else's facial expressions does not merely recruit a mirror-neuron matching system mediating the reproduction of specific emotional actions. This suggestion is in line with neuroimaging research in adults and children showing that the observation of facial expressions recruited both action representation networks (MNS) and limbic structures (e.g., amygdala, insula) involved in the appraisal/experience of others'emotional expressions/states (Carr, Iacoboni, Dubeau, Mazziotta, & Lenzi, 2003; Pfeifer, Iacoboni, Mazziotta, & Depretto, 2008).

The present study suggests that valence matching emerges after 3 months since only 7-month-olds and (more clearly) 12-month-olds showed a pattern of responses indicating that they selectively produced positive and negative facial expressions in response to the positive vs negative facial expressions of the model. Still, fewer than 50% of infants displayed valence-congruent responses. Although our paradigm, in which infants were exposed once to a given expression without social engagement with the model, might explain this moderate level of responding, our results are consistent with naturalistic studies using repeated modeling trials. In these studies, large individual differences (30 to 60%) were also found for the imitation of facial mimicry in human infants (Field, Goldstein, Vega-Lahr, & Porter, 1986; Heimann, 2002). However, since previous research involved younger infants, further studies are required on emotional mimicry in 7-12 month-olds under naturalistic conditions. Temperamental differences might explain such large interindividual variation in early imitation (Field et al., 1986).

In contrast, 3-month-olds displayed undifferentiated negative responding when exposed to positive, neutral or negative expressions of the model. The only congruent facial display in the youngest infants were smiles in response to the models'joy face. Social smiling is thought to emerge at around 2 months in the context of dyadic contingent interactions (Bigelow & Rochat, 2006; Soussignan et al., 2006), with familiarity of the partner (e.g., mother vs. a stranger) being a moderator of infants' smiling (Soussignan et al., 2009). In contrast with previous reports, in our study infants passively observed virtual models and, thus, were not actively engaged in contingent interactions. Nevertheless, despite the potential limitations of this design, in our study even the youngest infants responded with about 50% producing positive congruent reactions to the models' joy faces. Additionally, more 3-month-olds than 7-month-olds smiled to the models'joy face displaying a direct gaze. Previous naturalistic studies provided mixed findings, showing either the youngest or the oldest infants who smiled more in the context of dyadic exchanges (Bigelow & Rochat, 2006; Lin & Green, 2009; Rochat, Striano, & Blatt, 2002; Striano & Liszkowski, 2005). It has been argued that infants younger than 4 months are more attuned to mirror positive expressions of the social partner (i.e, stimulus-driven behavior), whereas after that age, infants progressively focus on the spatio-temporal contingencies that define the dynamics of social reciprocity (Rochat et al., 2002; Striano & Liszkowski, 2005). Thus, we suggest that the lack of social reciprocity and contingency provided by our experimental design might explain this developmental change in infants'smiling.

Furthermore, our results showed differences in valence matching between 7- and 12-month-olds: 12-months-old infants displayed negative expressions to the distinct negative expressions of the models (anger, disgust, fear, and sadness), whereas 7-month-olds reacted to the anger, fear and sad faces of the models. Research conducted in emotion-eliciting situations are consistent with the view that infants produce blended facial expressions of negative emotion rather than distinct types of negative facial expressions (Camras et al., 2007; Oster et al., 1992), with 12-month-olds being increasingly facially reactive to specific stimuli than younger infants (Bennett et al., 2005). Thus, our data do not support the DET. However, they appear consistent with the gradual differentiation, functionalist, and dynamical system theoretical frameworks proposing a progressive and partial differentiation of facial expressions with negative/blended expressions being more common in older than younger infants when exposed to distinct negative expressions of social partners.

Developmental changes in the infants' looking behavior toward facial expressions

Our data, based on video recordings of infant looking behaviors, showed that 7- and 12-month-olds looked longer at joy and fear faces than at neutral and anger faces. An interest for fear faces has been previously reported in behavioral and event-related potential (ERP) studies. Specifically, 7-month-olds look longer at fearful than at happy faces (Kotsoni et al., 2001), show attention-related ERPs to fearful faces (Peltola et al., 2009), and have difficulty in disengaging from fearful faces which is not attributable to their novelty (Peltola, Leppänen, Palokangas, & Hietanen, 2008). Some have speculated that this attentional bias towards fear faces reflects a bias toward certain configural features of the fear face or might reflect the interest for salient facial signals indicative of a threat/danger which would emerge around 7 months of age (Leppänen & Nelson, 2009; Peltola et al., 2008). The reasons why we did not find differences in infants' looking time at fear faces relative to joy faces could be due to differences in our procedure compared to other studies (dynamic vs. static faces; successive exposure to one facial stimulus vs. visual preference techniques).

As expected, we found developmental changes in infants'attention toward face regions conveying emotional information. Specifically, eye-tracking data showed ontogenetic changes in the way infants "read" expressions and visually explored them. In contrast to 3-month-olds, 7- and 12-month-olds showed a differential pattern of exploration of the model's face areas representing distinct emotional expressions. Our data are consistent with other studies indicating that the ability of fine-tuned processing of distinct emotional expressions is not yet established in 3-month-olds but emerges after the age of 5-6 months (Leppänen & Nelson, 2009; Nelson, 1987). In the present study, 7-and -12-month-olds looked longer at the eye, nose, and mouth areas that recruit muscle actions involved in fear, disgust and joy faces, respectively. These results likely reflect an attention to configural information of the face which emerges after 5 months (Leppänen & Nelson, 2009), rather than an interest in motion of the face which emerges earlier in infancy (Vinter, 1986).

Furthermore, the results indicate a developmental trend in that older infants showed a greater interest for some face regions involved in negative expressions. Twelve month-olds focused on the eye region for the fear face more than for other facial expressions, whereas 7 month-olds focused on the eye region of several negative emotions (fear, anger, sadness) more than for joy expresions. The eye region is an important feature for identifying fear faces and looking at the eye region of a fear face was related to a greater face-sensitive N290 amplitude in 7-month-olds (Vanderwert et al., 2015). Twelve month-olds also looked more at the nose region of the disgust face whereas the 7-month-olds looked longer at this area for the joy face. This finding could be an indicator of the developing ability to discriminate the social signaling value of specific facial movements, such as eye widening signaling a threat or nose wrinkling signaling rejection, which have been reported at the end of the first year (Sorce, Emde, Campos, & Klinnert, 1985).

The shorter duration of visual attention in the 3-month-olds at the mouth region for the models' joy expressions was unexpected because many of these infants smiled when exposed to those expressions, but also because other research, using a habituation paradigm, found that infants discriminate joy faces at this age (Barrera & Maurer, 1981; Young-Browne, Rosenfeld, & Horowitz, 1977). Our study suggests that 3-month-old infants can discriminate joy faces, without focusing at length on the relevant action of the mouth region. This interpretation is consistent with previous research showing that one or two short visual fixations are sufficient to recognize a face (Hsiao & Cottrell, 2008). It is also possible that this result is partly due to the duration of stimulus presentation in our study (i.e., 6 s), which might have been too short for young infants to engage in an extensive exploration of the mouth region. Future studies are needed to test this hypothesis.

Does the model's gaze direction influence infants' emotional mimicry?

According to the shared signal hypothesis proposed for adults (Adams & Kleck, 2005), the processing of approach-related emotions (anger and joy) is enhanced by direct gaze toward a perceiver, whereas the processing of avoidance-related emotions (fear, disgust, and sadness) is enhanced by an averted gaze. Our results do not provide evidence supporting such hypothesis in infants; they suggest that processing of gaze direction is not fully mature in infants, especially when gaze direction combined with facial expression, which provides information about communcative intent (e.g. fear), lacks a clear referent in the environment (Rigato et al., 2010). Rather, our findings showed that 3- and 12-months produced more positive or negative-congruent expressions when they established an eye contact with the model. Eye contact, at these ages, might be an important communicative cue fostering social attunement and engagement. Three-month-olds smiled more to joy face when the model directed its gaze towards them, which is line with research showing that young infants are sensitive to eye contact during positive exchanges (Hains & Muir, 1996). It has been proposed that 2-3 months is a transition age in terms of the emergence of infants'sensitivity to social contingencies and primary intersubjectivity (Striano & Liszkowski, 2005). This leaves open the possibility that the smiles of young infants are more easily driven by the adult's gaze because eye contact provides an additional cue to promote social engagement at an age where interactions are less reciprocal as compared to older infants (Rochat, Querido, & Striano, 1999). Regarding negative expressions, 12 month-olds, but not the 7-month-olds, showed more congruent expressions for both the approach-related (anger) and avoidance-related (fear and disgust) emotions when the model's gaze was directed toward them. Previous studies have shown that, compared to 10-months-olds, 12-months olds who passively observed positive or negative affect of an actress toward an object, attended to both gaze direction and negative emotional reactions of the adult to avoid the target object (Mumme & Fernald, 2003). Therefore, we propose that at the end of the first year, as social referencing abilities improve, infants can use both attentional (i.e., gaze) and negative facial cues to guide their behavior.

Limitations of the current study

They include the use of humanoid virtual models instead of real human faces which raises the question of ecological validity of the present study. Although virtual faces have the advantage to allow a stringent control on facial stimuli (e.g., emotional templates, gaze direction) and were shown to induce facial mimicry in adults (Soussignan et al., 2013), it is unclear whether infants are equally responsive to virtual models and human faces. However, although avatars may bear limitations in realism, they are increasingly used and exposure to them begins early in development (Bainbridge, 2007). Studies are needed comparing infants' responses toward both real and humanoid faces. Another limitation is the lack of social engagement between infants and avatars which might be one reason for the moderate percentage of infant performance on valence matching tasks. However, this seems unlikely since previous studies on facial mimicry in naturalistic contexts reported similar findings (Field et al., 1986; Heimann, 2002). A third limitation is that our design manipulated static gaze direction without a clear referent in relation to the infant. Thus, one cannot rule out that we did not provide enough information allowing infants to appraise the significance/behavioral intention of the avatars' facial expressions. Fourth, although the valence-congruent facial responses of infants were interpreted in the framework of a contextualized view of emotional mimicry, they might reflect related phenomena like emotional contagion or just infants' responses communicating a like or dislike to the facial expression of the model. Finally, our study did not control for factors contributing to individual differences. Future studies need to examine the effects of familiarity, social experience, temperament, or gene polymorphisms, which all could moderate emotional expressiveness (e.g., Grossmann et al., 2010; Soussignan et al., 2009).

In summary, the current study adds to our knowledge of emotional sensitivity shown by infants in response to emotions expressed by a model suggesting that valence-congruent expressions develop during a period of fine-tuning when infants become more sensitive to the meaning and social value of facial expressions.

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Figure captions

Figure 1 Areas of interest (AOIs) of the virtual models' faces used during the experiment: Eyes area in dark blue, Nose area in light blue, Mouth area in pink and External Traits area in orange.

Figure 2 Infants' looking time (%) to the screen showing the virtual models' emotional expressions. For the video data, looking time % was calculated by dividing the infants' looking time to the screen on the total time of the trial (error bars correspond to standard errors); * $p < .05$, ** $p < .01$ (at 7 months, joy and fear > neutral; joy > anger. At 12 months, joy and fear > neutral and anger).

Figure 3 Infants' looking time (in ms) at the face regions (eyes, nose, mouth, external features) of the virtual model using the eye-movement tracking technique according to the infants' age (3-, 7-, and 12-month-olds) and the models' facial expressions (error bars correspond to standard errors); *$p < .05$, ** $p < .01$, *** $p < .001$ (Eyes area: at 7 months, anger, fear and sadness > joy; fear > neutral; at 12 months, fear > neutral, joy, disgust, anger and sadness. Nose area: at 7 months, joy > anger and fear; at 12 months, disgust > neutral and anger; disgust and joy > fear. Mouth area: at 7 and 12 months, joy > neutral, anger, disgust, fear and sadness).

Infants' facial responses / Models' facial expressions	3 months						7 months						12 months					Intra-task Comparisons
	AU 12	**AU 4+24**	**AU 9**	**AU 1+2+4+5+20**	**AU 1+4+15**	Q (df=4)	**AU 12**	**AU 4+24**	**AU 9**	**AU 1+2+4+5+20**	**AU 1+4+15**	Q (df=4)	**AU 12**	**AU 4+24**	**AU 9**	**AU 1+2+4+5+20**	**AU 1+4+15**	Q (df=4)
Neutral-Dir	4(11.1)	2(5.5)	1(2.8)	8(22.2)	0(0)	13.33**	1(2.9)	2 (5.7)	1(2.9)	6(17.1)	0(0)	11.58*	3(9.1)	3(9.1)	1(3)	3(9.1)	3(9.1)	4.0
Neutral-Av	5(13.9)	3 (8.3)	2(5.5)	2(5.5)	0(0)	5.74	2(5.7)	0(0)	0(0)	9(25)	1(2.9)	24.87***	2(6.1)	3(9.1)	1(3)	3(9.1)	3(9.1)	3.78
Joy-Dir	15(41.7)	1(2.8)	1(2.8)	3(8.3)	1(2.8)	**38.15*** **	5(14.3)	1(2.9)	0(0)	0(0)	0(0)	**15.66** **	9(27.3)	2(6.1)	1(3)	0(0)	0(0)	**23.83*** **
Joy-AV	9(25)	3(8.3)	0(0)	7(19.44)	0(0)	**18.05*** **	5(14.3)	0 (0)	0(0)	3(8.6)	0(0)	**14.13** **	11(33.3)	1(3)	2(6.1)	2(6.1)	1(3)	**23.61*** **
Anger-Dir	2(5.5)	4(11.1)	2(5.5)	10(27.8)	0(0)	16.44**	2(5.7)	1(2.9)	2(5.7)	6(17.1)	0(0)	9.45*	1(3)	5(15.1)	1(3)	2(6.1)	0(0)	8.22
Anger-Av	5(13.9)	8(22.2)	2(5.5)	11(30.5)	0(0)	16.76**	2(5.7)	4(11.4)	1(2.9)	8(22.9)	0(0)	12.93*	3(9.1)	4(12.1)	3(9.1)	1(3)	1(3)	3.13
Disgust-Dir	3(8.3)	4(11.1)	2(5.5)	5(13.9)	0(0)	5.48	2(5.7)	1 (2.9)	2(5.7)	1(2.9)	0(0)	2.33	4(12.1)	2(6.1)	2(6.1)	1(3)	0(0)	5.18
Disgust-Av	4(11.1)	3(8.3)	2(5.5)	6(16.7)	0(0)	6.89	2(5.7)	3 (8.6)	1(2.9)	4(11.4)	0(0)	5.26	1(3)	4(12.1)	1(3)	3(9.1)	1(3)	4.21
Fear-Dir	4(11.1)	3(8.3)	2(5.5)	9(25)	0(0)	12.91*	2(5.7)	2(5.7)	0(0)	6(17.1)	1(2.9)	9.90*	4(12.1)	4(12.1)	0(0)	2(6.1)	0(0)	8.0
Fear-Av	7 (19.4)	5(13.9)	2(5.5)	9(25)	0(0)	12.67*	0(0)	4(11.4)	0(0)	3(8.6)	1(2.9)	8.25	2(6.1)	2(6.1)	0(0)	4(12.1)	0(0)	7.47
Sad-Dir	3(8.3)	5(13.9)	1(2.8)	6(16.7)	0(0)	8.97	2(5.7)	1(2.9)	0(0)	6(17.1)	0(0)	14.58**	2(6.1)	6(18.2)	0(0)	2(6.1)	1(3)	9.9*
Sad-Av	4 (11.1)	3(8.3)	0(0)	8(22.2)	1(2.8)	12.52*	0(0)	9(25.7)	2(5.7)	8(22.9)	2(5.7)	16.61**	3(9.1)	4(12.1)	0(0)	1(3)	2(6.1)	5.26
Inter-task Comparions Q (df=11)	**33.89** **	10.79	5.22	10.06	11.0		**19.5***	25.08**	11.0	23.91**	11.0		**31.39** **	10.20	12.22	11.87	11.0	

Table 1. Number and percentage (in parentheses) of infants who displayed emotion-congruent facial actions when they passively watched facial expressions of virtual models with direct (Dir) or averted (Av) gaze. Cochran Q tests were used to compare infants' facial responses to the models' facial expressions in the inter-task comparisons (inter-situational specificity) and in the intra-task comparisons (intra-situational specificity); AU 1: Inner brow raising, AU 2: Outer brow raising, AU 4: Brow lowering, AU 5: Upper lid raising, AU 9: Nose wrinkling, AU 12: Lip corner pulling, AU 15: Lip corner depressing, AU 20: Lip stretching, AU 24: Lip pressing, * *p < .05; *** *p< .01; **** *p < .001.*

	NeutralDir	NeutralAv	JoyDir	JoyAv	AngerDir	AngerAv	DisgustDir	DisgustAv	FearDir	FearAv	SadDir	SadAV
3 months (n=36)	12 (33.3)	11 (30.5)	6 (16.7)	10 (27.8)	15 (41.7)	16 (44.4)	10 (27.8)	15 (41.7)	13 (36.1)	14 (38.9)	13 (36.1)	16 (44.4)
7 months (n = 35)	6 (17.1)	10 (28.6)	3 (8.6)	2 (5.7)	9 (25.7)	9 (25.7)	9 (25.7)	8 (22.8)	8 (22.8)	12 (34.3)	8 (22.8)	19 (54.3)
12 months (n=33)	3 (9.1)	4 (12.1)	3 (9.1)	4 (12.1)	11 (33.3)	9 (27.3)	10 (30.3)	5 (15.1)	10 (30.3)	5 (15.1)	9 (27.3)	10 (30.3)

Table 2. Number and percentage (in parentheses) of infants who displayed negative facial responses when they passively watched facial expressions of virtual models with direct (Dir) or averted (Av) gaze.

Supporting Information

Supplementary Table 1. Face regions of the virtual characters (eyes and eyebrows, nose, mouth) containing specific action units (AUs) which are relevant for each facial expression and corresponding to facial expressions of emotion predicted to be more fixated by infants using eye-movement tracking technique.

Figure 1 Areas of interest (AOIs) of the virtual characters'faces used during the experiment: Eyes area in dark blue, Nose area in light blue, Mouth area in pink and External Traits area in orange.

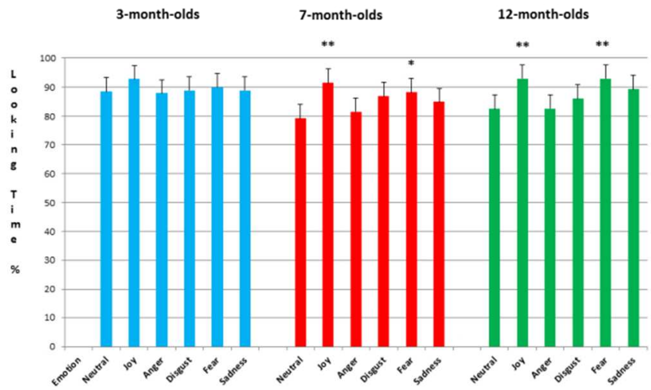
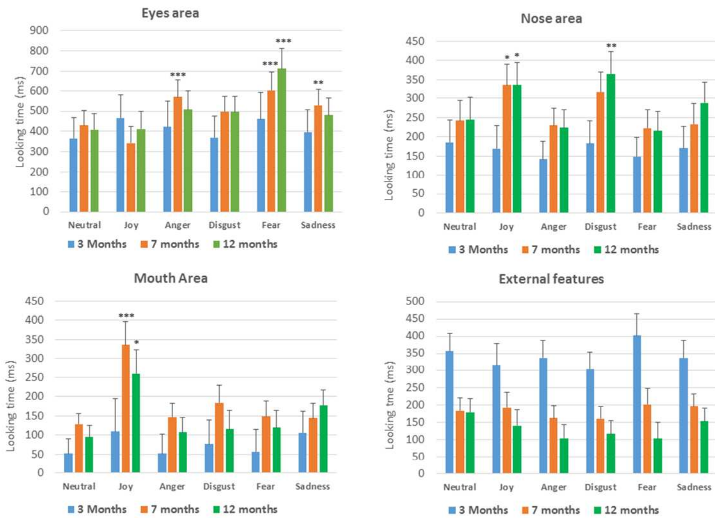


Figure 2 Infants' looking time (%) to the screen showing the virtual models' emotional expressions. For the video data, looking time % was calculated by dividing the infants' looking time to the screen on the total time of the trial (error bars correspond to standard errors); * p < .05, ** p < .01 (at 7 months, joy and fear > neutral; joy > anger. At 12 months, joy and fear > neutral and anger).

130x73mm (200 x 200 DPI)



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338x190mm (96 x 96 DPI)

Supplementary Table 1. Face regions (eyes and eyebrows, nose, mouth) of the virtual characters containing specific action units (AUs) which are relevant for each facial expression and corresponding to facial expressions of emotion predicted to be more fixated by infants using eye-movement tracking technique.

Expressions \ Regions	Eyes & Eyebrows	Nose	Mouth
Anger	Brow lowering (AU 4)		Lip pressing (AU 24)
Disgust		Nose wrinkling (AU 9)	
Fear	Eyebrow raising, Upper lid raising (AUs 1+2+4+5, AUs 1+2, AU5)		Lip stretching (AU 20)
Sadness	Brow raising and Brow pulled together (AUs 1+4)		Lip depressing (AU 15)
Joy			Lip corner pulling (AU 12)